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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : H04L 27/01

A2

(11) International Publication Number: WO 98/48545

(43) International Publication Date: 29 October 1998 (29.10.98)

(21) International Application Number: PCT/FI98/00353

(22) International Filing Date: 21 April 1998 (21.04.98)

(30) Priority Data:
971760 24 April 1997 (24.04.97) FI

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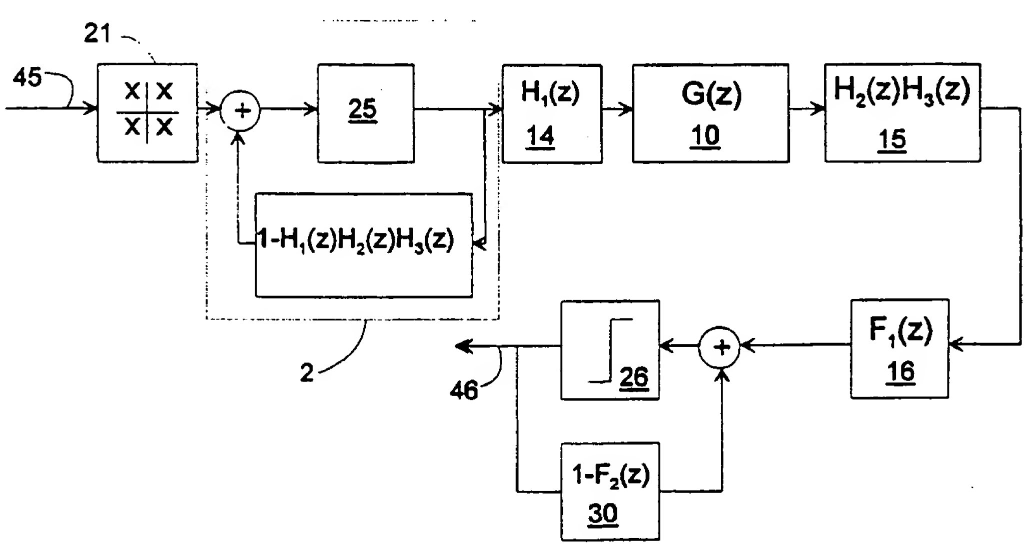
(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, GM, GW, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).

Published
In English translation (filed in Finnish).
Without international search report and to be republished upon receipt of that report.

(54) Title: METHOD AND APPARATUS FOR PROCESSING A SIGNAL IN A TELECOMMUNICATION APPARATUS



(57) Abstract

The invention relates to a method and an apparatus for processing a signal in a telecommunication apparatus. According to the method the signal is fed to a telecommunication channel (10), the signal is processed with a linear adaptive receiver equalizer (16) and possibly a decision feedback adaptive equalizer (30). According to the invention the equalization (H(z)) of the sections of the fixed band stop filters (14, 15) located in the transmitter (50) and the receiver (60) is performed at the transmitter end (50) prior to the band stop filtering (14) of the transmitter (50).

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Method and apparatus for processing a signal in a telecommunication apparatus

The invention relates to a method according to the preamble of claim 1 for processing a signal in a telecommunication apparatus.

The invention also relates to an apparatus for processing a signal in a telecommunication apparatus.

Ever-increasing speeds will be used for transfer via a subscriber line of copper. An ETSI team is currently working on the definition of the so called VDSL modem (Very high speed Digital Subscriber Line) where the greatest transfer speed may reach as high as 52 Mbit/s. Hereby the bandwidth of the modulated signal may even be in the range of 10 MHz.

With a bandwidth of several MHz different kinds of radio frequency interference begin to pose problems particularly in countries where aerial cables are used as subscriber lines (for instance in the Finnish countryside). The modem receiver may be interfered with by AM radio stations and radio amateur stations whose transmitted radio waves may be connected to the aerial cable, partly becoming so called transversal interference in a twisted pair and being conveyed to the modem receiver, interfering with it. A modem may, on the other hand, interfere with listening in on AM radio channels or with a radio amateur's reception because a modulated signal travelling in a twisted pair contains power at said radio frequencies and this power is partly emitted into the environment.

Problematic radio bands are listed in Table 1.

International radio amateur bands	
Beginning of band (MHz)	End of band (MHz)
1.810	2.000
3.500	3.800

7.000	7.100
10.100	10.150
14.000	14.350
18.068	18.168
21.000	21.450
24.890	24.990
28.000	29.700

TABLE 1

Radio interference caused by a transmitter may be eliminated by removing by filtering from the spectrum of a modulated signal the frequencies which are within the bands causing problems.

Radio interference connected to the cable, causing problems in the receiver, can be filtered by using suitable band stop filters which may be analog or digital or both. In fast modems signal processing is mainly digital wherefore a received signal is converted into numeric form by means of an analog-to-digital converter (A/D converter). As the level of the radio interference may be high compared to the received effective signal, it would be of advantage for the dynamics of the A/D converter if at least a part of the radio interference filtering took place before the A/D conversion by means of a band stop filter implemented using analog techniques.

The operation of the adaptive line equalizer is made difficult if a modem signal is filtered in the transmitter, the receiver or both, because the filters change the transfer function and the impulse response or the so called system response of the entire signal path. Filters give rise to additional distortion which even contains transmission zeros in the problematic radio frequency bands. Band stop filters of narrow bandwidth are particularly problematic from the point of view of receiver equalizers because equalizing them requires time-wise very long adaptive equalizers.

Reference /1/ (p. 574 to 577) describes a mechanism in the transmitter of a modem by means of which it is possible to provide transmission zeros in the transmission spectrum at desired frequencies without hampering the operation of the receiver. By the method band stop filters filtering radio interference can be made "invisible" for the adaptive line equalizer whereby the adaptive equalizers do not need to take part in equalizing the distortion of the system response caused by these band stop filters. The method is suited for modems making use of generally known linear modulation methods: PAM modulation (Pulse Amplitude Modulation), QAM modulation (Quadrature Amplitude Modulation) or CAP modulation (Carrierless Amplitude/Phase coding).

The method is based on the use of the so called Tomlinson-Harashima precoding (in the following termed Tomlinson coding). In the original Tomlinson coding method distortion caused by the channel or part of the distortion is corrected by means of a filter in the transmitter. QAM and CAP modulation produce signals which are of the bandpass type. In these cases the examination can, however, always be carried out by using the commonly known, so called baseband equivalent channel model where the transfer function of the transmission channel is transferred to the baseband and the channel is modelled using a complex baseband transfer function and a complex impulse response. Thus the whole examination can be performed by studying the baseband system.

The aim of the present invention is to remove the disadvantages hampering the above-described techniques and to provide an entirely novel type of method and apparatus for processing a signal in a telecommunication apparatus.

The invention is based on the equalizer correcting the fixed part H(z) being transferred to the transmitting end of the apparatus.

In more detail the method according to the invention is characterized by what is stated in the characterizing part of claim 1.

The apparatus according to the invention, then, is characterized by what is stated in the characterizing part of claim 6.

The invention provides considerable benefits.

Radio-frequency interference is effectively filtered without hampering reception.

In the following, the invention is examined in more detail with the aid of a number of working examples with reference to the annexed Figures.

Fig. 1 illustrates a prior-art adaptive equalizer.

Fig. 2 illustrates another prior-art equalizer.

Fig. 3 illustrates a third prior-art equalizer.

Fig. 4 shows an apparatus according to the invention.

Fig. 5 shows another alternative apparatus according to the invention.

Fig. 6 depicts a third alternative apparatus in accordance with the invention.

Fig. 7 illustrates an alternative solution according to the invention to the solution of Fig. 5.

Fig. 8 illustrates an alternative solution according to the invention to the solution of Fig. 6.

In the following description, Z transformation is used to describe transfer functions at the frequency domain.

The following reference numerals are used in the following description to refer to components of the invention or other relevant components.

Tomlinson coder	1
Modified Tomlinson coder	2
Second modified Tomlinson coder	3
Third modified Tomlinson coder	4
Signal value	5
Level control	6
Adder	7
Feedback	8a to 8c
Telecommunication channel	10
Transmitter band stop filter	14
Receiver band stop filter	15
Linear adaptive equalizer	16
Mapping from bits to symbols	21
Modulo-operator	25
Expanded detector (slicer)	26
Adaptive decision-feedback equalizer	30
Detector	35
Transmitted bits	45
Detected symbol	46
Transmitter	50
Receiver	60
Fourth modified Tomlinson coder	100
Fifth modified Tomlinson coder	101

Fig. 1 shows a commonly known adaptive DFE equalizer (cf., e.g., /1/, p. 474) where the adaptive equalizer comprises a linear section 16 ($1/G_1(z)$) and a feedback section 30 ($1 - G_2(z)$) which together equalize the transfer function $G_1(z)G_2(z)$ of channel 10. In addition

to the transfer function of the channel itself the transfer function $G_1(z)G_2(z)$ also contains the fixed filters of the transmitter 50 and the receiver 60. In block 21 the bit stream 45 entering the transmitter is grouped into groups having a length of N bits and these groups of bits are described as one- or two-dimensional symbols. Hereby one symbol conveys N bits of information. In the following the transmitter 50 and the receiver 60 are not separately described but it will be obvious to a person skilled in the art that they are located on both sides of the channel 10, in this presentation such that the transmitter 50 is mainly described on the left-hand side of the figures, the arrows which represent the flow of information progressing from the transmitter 50 towards the receiver 60.

Fig. 2 shows a commonly known construction making use of Tomlinson precoding. The feedback coupled transfer function 30 ($1-G_2(z)$) contained in the coder 1 of the transmitter corrects the section $G_2(z)$ in the transfer function of the channel 10. The feedback loop contains a modulo-operation 25 by means of which the transmission power of the transmitter can be kept constant in spite of the feedback. Using a modulo-operation 25 requires the use of a so called expanded slicer 26 in the receiver. Tomlinson coding and the use of an expanded slicer is a commonly known method which is described, among other sources, in reference /1/ (p. 460 to 464).

In Fig. 3, band stop filters 14 and 15 are added to the transmitter and the receiver, said filters filtering the signal power of both a transmitted and a received signal at frequencies where the modem may interfere with external radio receivers or where the modem receiver may be interfered with when a signal transmitted by external radio transmitters is connected to a line coupled to the receiver. The transfer function of the channel is indicated by $G(z)$. The band stop filter 15 of the receiver may contain the transfer function $H_2(z)$ of an analogue filter and the transfer function $H_3(z)$ of a digital filter. The analog section $H_2(z)$ is a baseband equivalent of the transfer function of the actual analog filter, because this transfer function is reflected via a frequency modulation in the QAM demodulation or CAP filtering of the receiver. In baseband modems the transfer function $H_2(z)$ directly corresponds to the transfer function of the analog filter. $H_1(z)$ is the

transfer function of the band stop filter at the transmission end.

The construction of Fig. 3 is a functional system as such. The adaptive equalizers 16 ($F_1(z)$) and 30 ($1-F_2(z)$) now have to equalize not only the distortion caused by the channel but also the transfer function $H_1(z)H_2(z)H_3(z)$ caused by the band stop filters 14 and 15. Below, this transfer function is labelled $H(z)$. As $H(z)$ is in practice of narrow bandwidth, the equalizers $F_1(z)$ and $1-F_2(z)$ (in practice adaptive FIR filters) must be made of very long duration, whereby their implementation becomes difficult to calculate. A filter which compensates band stop filters could be implemented by means of a fixed filter which would be connected in cascade with the adaptive feedback equalizer. The shared transfer function of the feedback equalizer would then be $1-F_2(z)H(z)$ where F_2 is the adaptively controlled section and H the fixed section. It is known, however, that controlling the adaptive section would be very problematic with such a cascade connection. In addition, it is known that using trellis coding would be very difficult if the receiver equalizer were to contain a feedback section.

The above-described system can be improved by transferring the fixed equalizer which equalizes the $H(z)$ section to the transmission end in accordance with Fig. 4. As the feedback filter 2 of Fig. 4 may be unstable, a modulo-operation 25 has been added to the mechanism 2 in the manner of a Tomlinson coder. Hereby it is necessary to apply an expanded slicer geometry 26 in the receiver. The basic principle of the method is described in the above-cited reference /1/ (p. 574 to 576) where an outgoing signal is filtered using a band stop filter and the effect of said filter is corrected using Tomlinson coding such that the operation of the receiver is not hampered. In this invention the method is expanded such that even the band stop filters in the receiver are "corrected" by means of the Tomlinson coding 2 at the transmitting end, whereby the band stop filters 14 and 15 do not hamper the operation of the line equalizer of the receiver.

The feedback section 30 ($1-F_2(z)$) of the equalizer of the receiver in Fig. 4 can be transferred to the transmitter to form part of the feedback filter chain of the Tomlinson

coder. Fig. 5 illustrates this method where the filter $F_2(z)$ is transferred to form part of the feedback filter chain of the transmitter, the transfer function of the feedback filter 3 hereby being $1-H_1(z)H_2(z)H_3(z)F_2(z)$. The receiver then only contains the linear equalizer 16 in front of the slicer 26, this making the use of channel coding possible. That it is very difficult to use channel coding if the receiver equalizer contains a feedback section is generally known (e.g. /1/, p. 464).

The implementation of the feedback filter in the transmitter of Fig. 5 is often easier if the filter is divided into smaller blocks in cascade connection in accordance with block 4 in Fig. 6. The transfer functions of the filters of the transmitters in Figs. 5 and 6 are the same if the effect of the modulo-operation is not taken into account. The modulo-operation cannot be carried out in accordance with the original Tomlinson coder; instead, a modified method is shown in Fig. 6. The aim is, as in Tomlinson coding, to keep the signal 5 level within the limits -M and M, where M is associated with the signal geometry used such that the relative values of the coordinates of the points in said geometry are

$$-(M-1),-(M-3),\ldots -3,-1,+1,+3,\ldots,(M-3),(M-1)$$

The mechanism depicted in Fig. 6 operates as follows:

a) taking the next symbol value from the symbol description block

b) calculating a filter chain whereby a value is obtained for the signal 5

c) checking in the level control block 6 whether the signal 5 is between the limits - M and +M, and if not, the adder 7 is used to sum a value kM into the input to the filter, where k is a positive or negative integer, such that the signal 5 after this correction is within the target limits -M and M

d) a signal containing the correction term kM calculated above is taken to the feedback connections 8a, 8b, 8c and 5 of the filter; then the correction term is contained in the output signal 5 of the entire filter, keeping it within the desired limits, and in signals fed to the feedback connections of all partial filters.

If two-dimensional signal geometry is used, the above-described level control must be performed separately for both coordinates.

In the same way as a conventional Tomlinson coder (/1/, p. 460 to 464) is analysed, it can be shown that the outgoing signal 5 of the above-described coder is approximately evenly distributed between -M and +M and that successive samples do not correlate with one another. Thus, the spectrum of the outgoing signal before the band stop filters is white, and the coder does not significantly alter the level of the outgoing signal 5.

The above-described mechanism requires that an expanded detector be used in the receiver. This expanded detector is similar to the expanded detector used with the original Tomlinson coder.

The mechanism of Figs. 5 and 6 can be simplified in accordance with Figs. 7 and 8 by either modifying the digital band stop filter $H_1(z)$ of the transmitter or the digital band stop filter $H_3(z)$ of the receiver such that it is of greater width than the other filters, such that the transfer function of this wider filter alone (with a certain accuracy) determines the transfer function which is common to all band stop filters. Then, if e.g. the stop band of $H_1(z)$ is modified such that it is wider than the others, the following is true:

$$H_1(z)H_2(z)H_3(z) = H_1(z) \quad (1)$$

Then the feedback filter of the transmitter is simplified because the section incorporating $H_2(z)$ and $H_3(z)$ can be omitted whereby the filter merely contains $H_1(z)$.

The method further provides the benefit that the implementation tolerances of the analog band stop filter do not pose problems, if the above condition (1) is met with sufficient accuracy even within the scope of the variations due to the inaccuracy of the components of the analog filter.

Reference /1/: Edward A. Lee, David G. Messerschmitt: Digital Communication, Kluwer Academic Publishers.

Claims:

1. A method for processing a signal in a telecommunication apparatus, in which method

- the signal is fed to a telecommunication channel (10),

- the signal is processed using a linear adaptive reception equalizer (16) and possibly a decision-feedback adaptive equalizer (30),

characterized by

- performing the equalization (H(z)) of the section relating to the fixed band stop filters (14, 15) in the transmitter (50) and the receiver (60) at the transmitting end (50) prior to the band stop filtering (14) of the transmitter (50).

2. The method of claim 1, **characterized** by transferring the feedback section (30) of the equalizer of the receiver (60) to form part of the feedback filter chain of a modified Tomlinson coder (3).

3. The method of claim 1, **characterized** by the modified Tomlinson coder (4) being formed by several successive filter blocks (8a, 8b, 8c, 30) which are feedback connected by means of a level control block (8).

4. The method of claim 1, **characterized** by

- selecting the width of the stop band of the digital band stop filter (14) of the transmitter greater than the widths of the stop bands of the band stop filters (15) of the receiver, and

- the feedback connection of the modified Tomlinson coder (100) containing a section corresponding to the band stop filter (14) of the transmitter and the feedback section (30) of the equalizer transferred from the transmitter (60).

5. The method of claim 1, **characterized** by

- selecting the width of the stop band of the digital band stop filter (14) of the transmitter such that it is greater than the widths of the stop bands of the band stop filters (15) of the receiver, and

- the feedback connection of the modified Tomlinson coder (101) containing a section corresponding to the band stop filter (14) of the transmitter and the feedback section (30) of the equalizer transferred from the transmitter (60).

6. An apparatus for processing a signal in a telecommunication apparatus, the apparatus comprising

- a transmitter part (50),

- a signal path (10),

- a receiver (60) and

- an adaptive equalizer (16) adapted in the signal path and possibly an adaptive decision feedback equalizer (30) connected to a detector,

characterized in that

- the equalizer (H(z)) of the fixed band stop filters (14, 15) in the transmitter (50) and the receiver (60) is located at the transmitter end prior to the band stop filter (14).

7. The apparatus of claim 6, characterized in that the feedback section (30) of the receiver (60) equalizer is transferred to form part of the feedback filter chain of a modified Tomlinson coder (3).

8. The apparatus of claim 6, characterized in that the modified Tomlinson coder (4) is formed of several successive filter blocks (8a, 8b, 8c, 30) which are feedback connected by means of a level control block (8).

9. The apparatus of claim 6, characterized in that

- the width of the stop band of the digital band stop filter (14) of the transmitter is greater than the widths of the stop bands of the band stop filters (15) of the receiver, and

- the feedback connection of the modified Tomlinson coder (100) incorporates a section corresponding to the band stop filter (14) of the transmitter and the feedback section (30) of the equalizer transferred from the transmitter (60).

10. The apparatus of claim 6, characterized in that

- the width of the stop band of the digital band stop filter (14) of the transmitter is greater than the widths of the stop bands of the band stop filters (15) of the receiver, and

- the feedback connection of the modified Tomlinson coder (101)

incorporates a section corresponding to the band stop filter (14) of the transmitter and the feedback section (30) of the equalizer transferred from the transmitter (60).

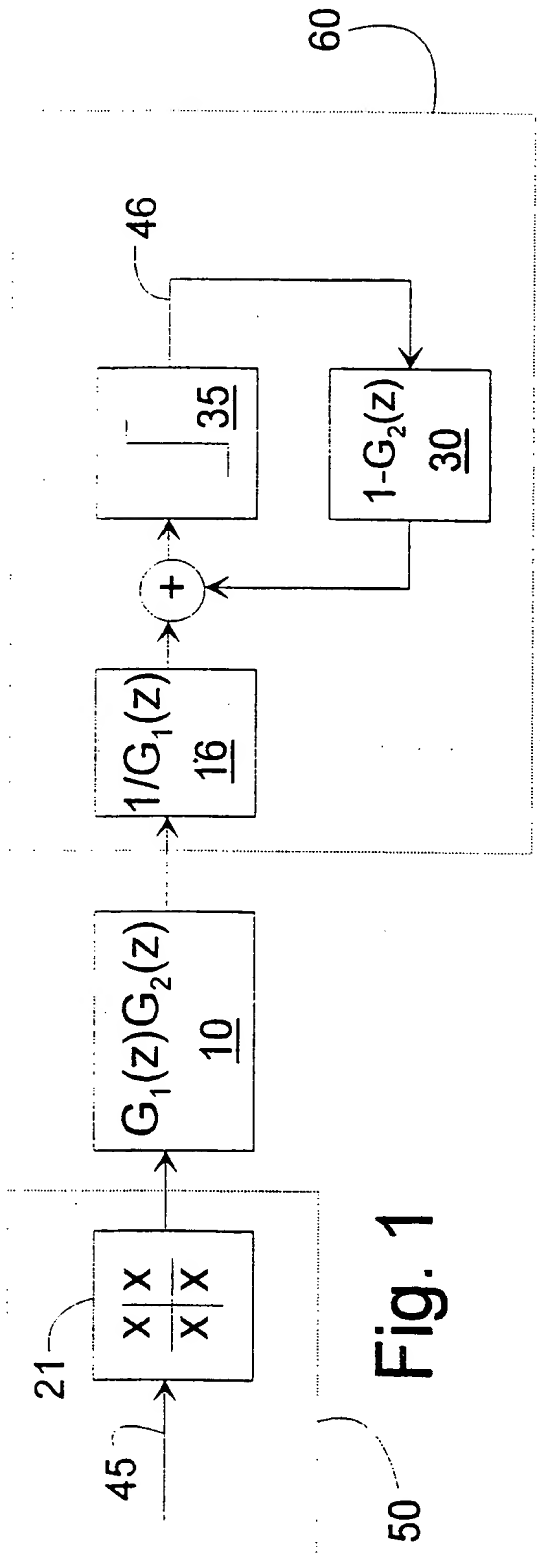
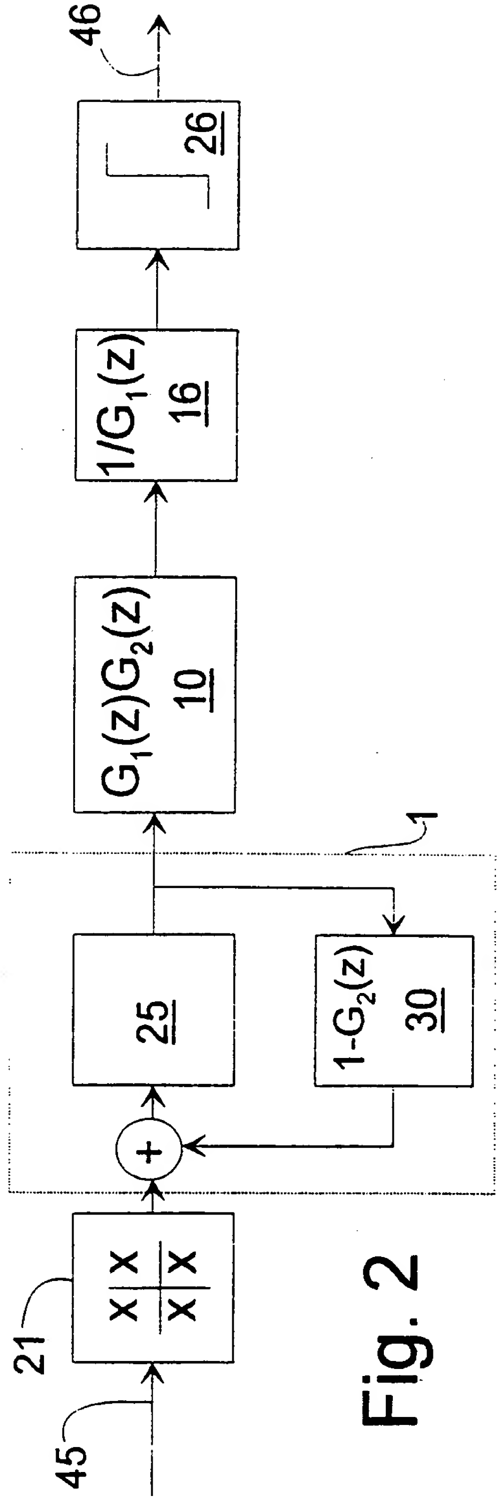

60
46
35
1-G2(z)
30
1/G1(z)
16
G1(z)G2(z)
10
21
45
50

Fig. 1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26
1/G1(z)
16
G1(z)G2(z)
10
1
25
1-G2(z)
30
21
45

Fig. 2

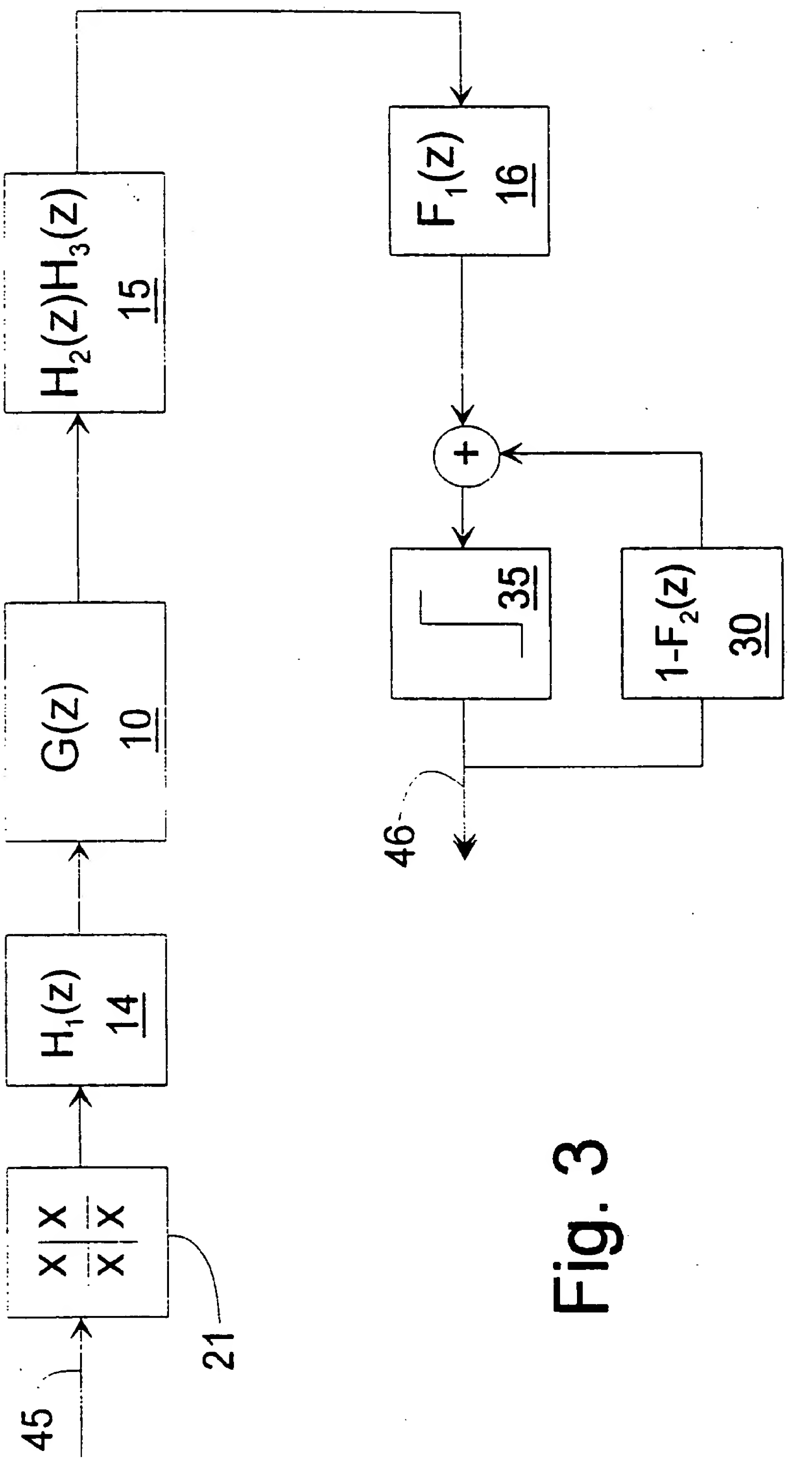


Fig. 3

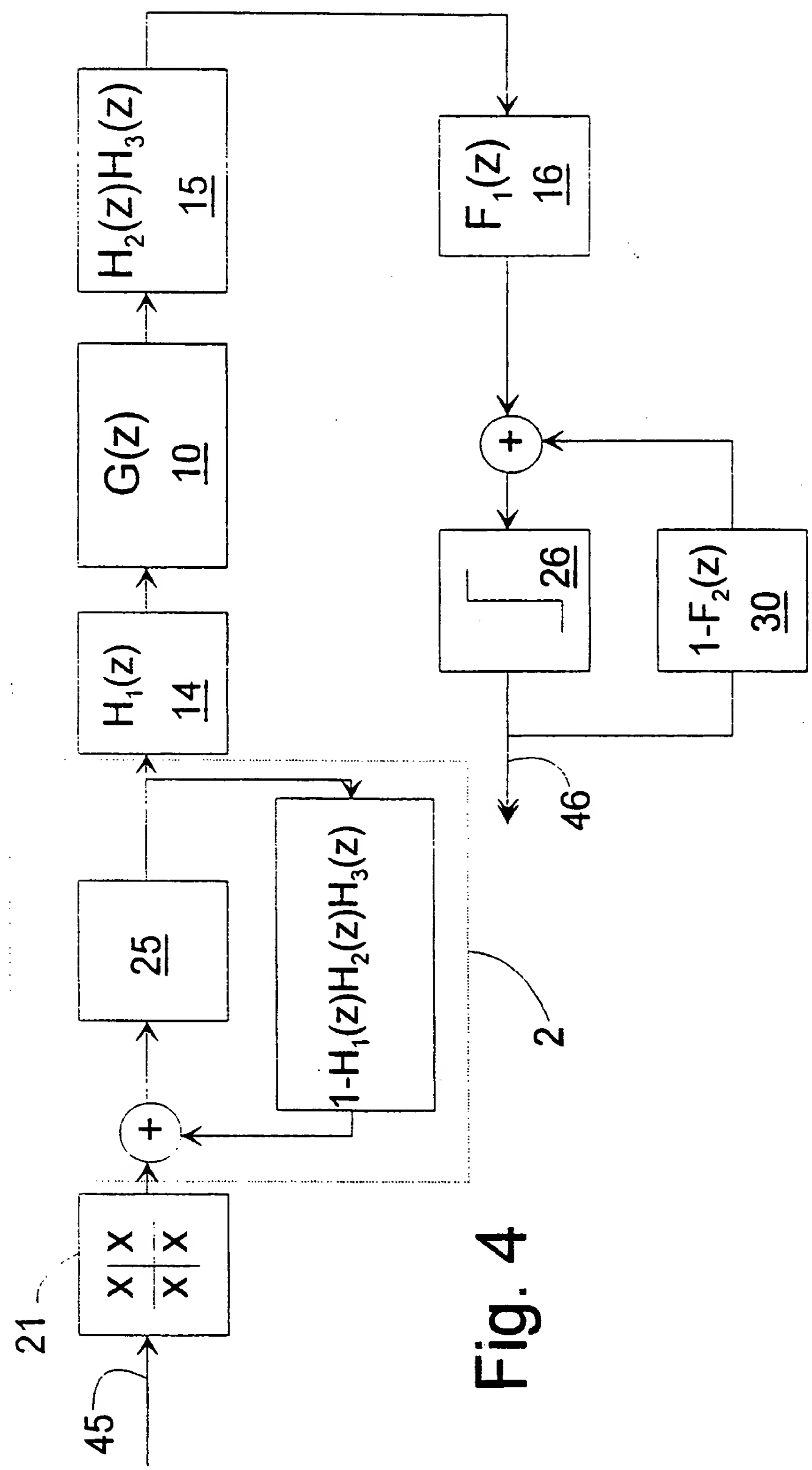


Fig. 4

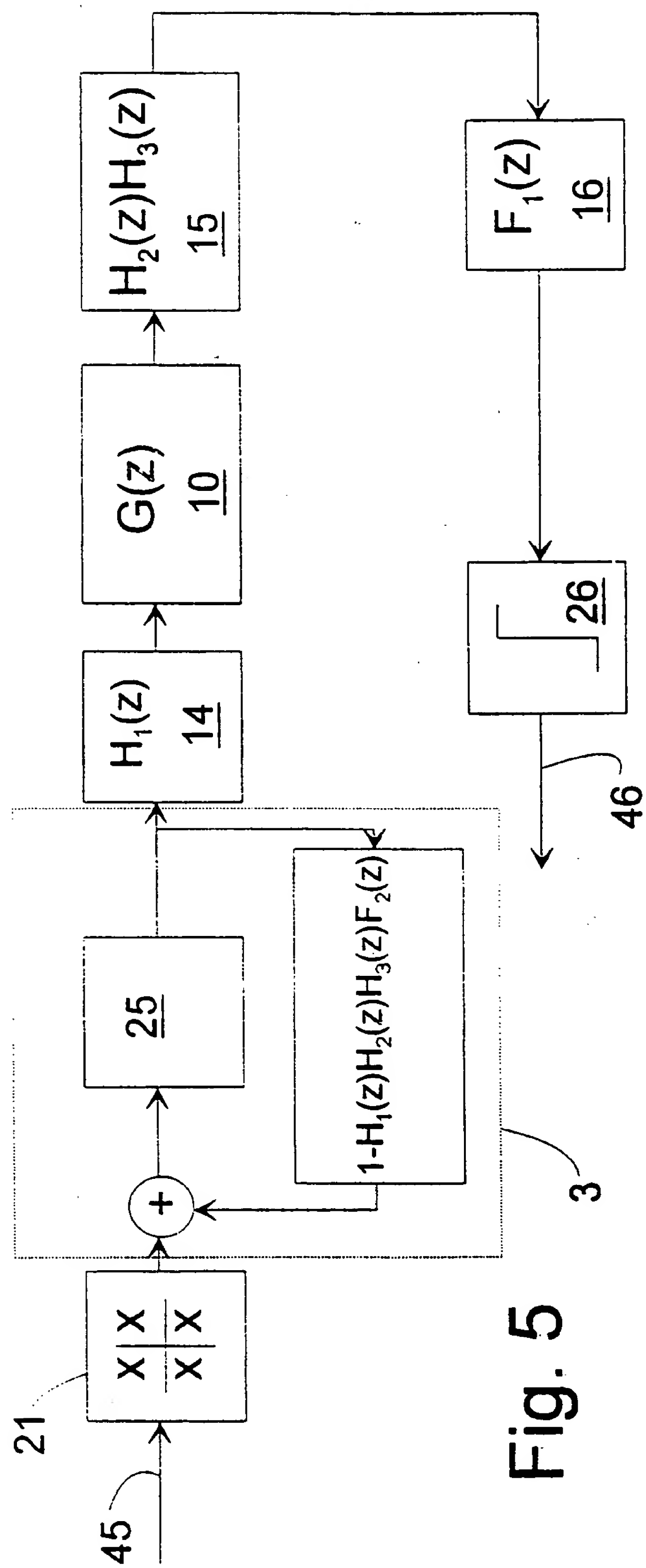
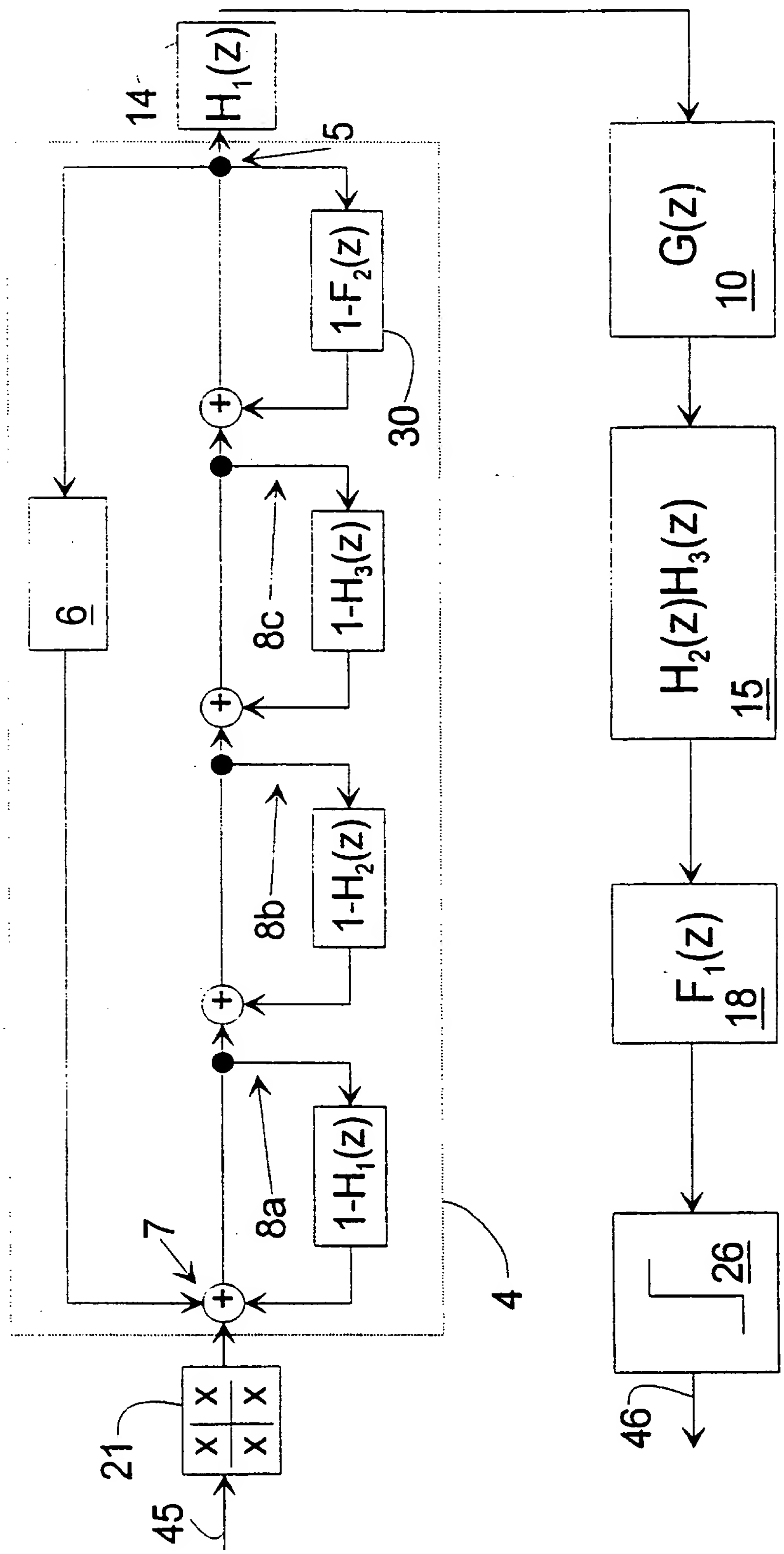


Fig. 5



14
$H_1(z)$
5
$1-F_2(z)$
30
$1-H_3(z)$
8c
6
$1-H_2(z)$
8b
$1-H_1(z)$
8a
7
4
21
45
$G(z)$
10
$H_2(z)H_3(z)$
15
$F_1(z)$
18
26
46

Fig. 6

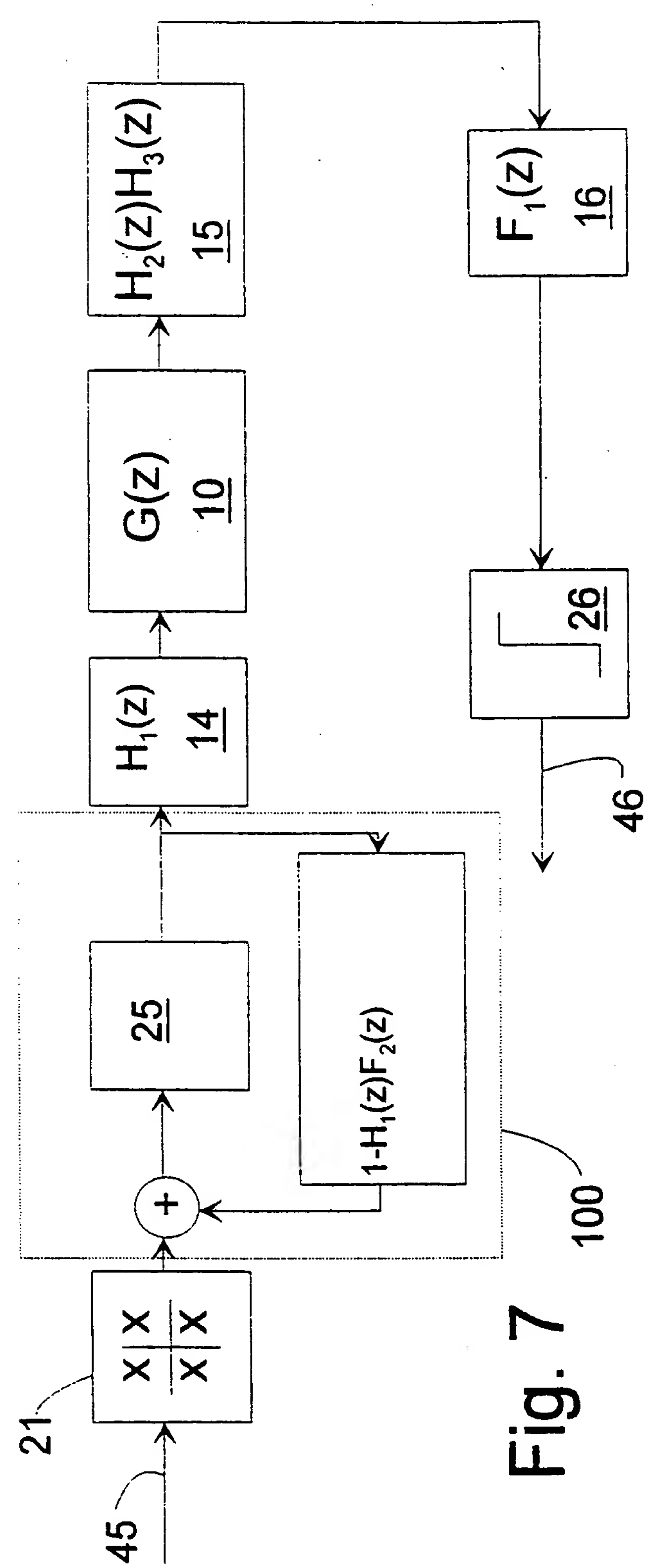


Fig. 7

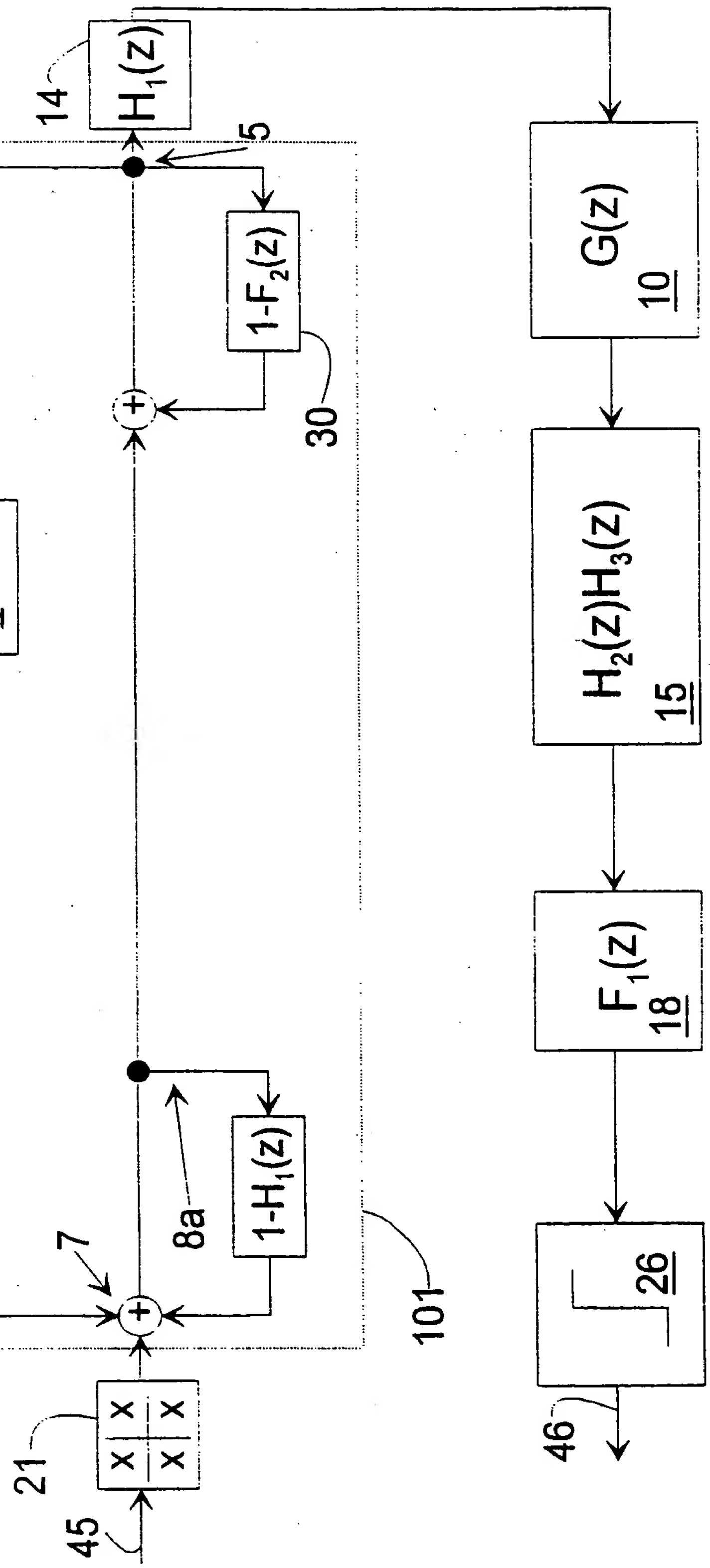


Fig. 8

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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : H04L 27/01

A3

(11) International Publication Number: WO 98/48545

(43) International Publication Date: 29 October 1998 (29.10.98)

(21) International Application Number: PCT/FI98/00353

(22) International Filing Date: 21 April 1998 (21.04.98)

(30) Priority Data:
971760 24 April 1997 (24.04.97) FI

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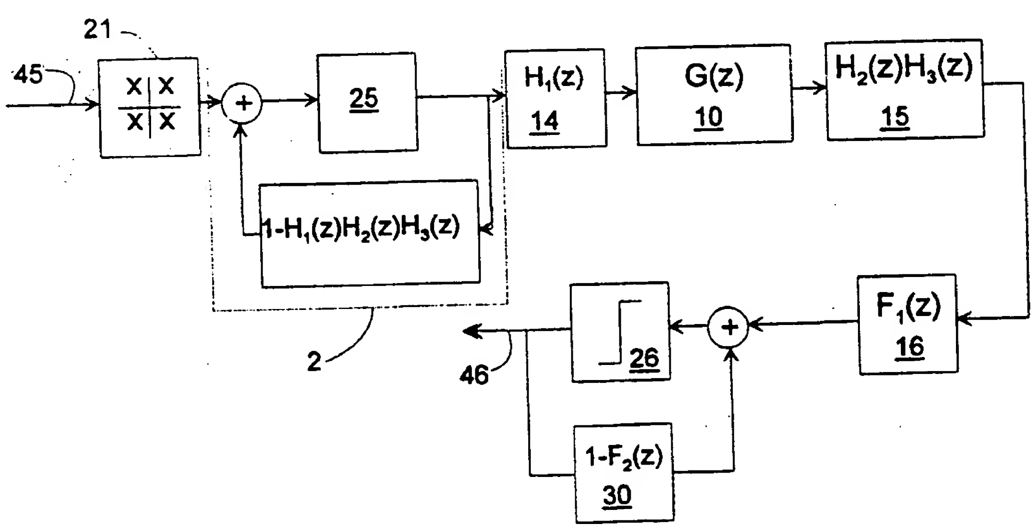
(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, GM, GW, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).

Published
With international search report.
In English translation (filed in Finnish).

(88) Date of publication of the international search report: 21 January 1999 (21.01.99)

(54) Title: METHOD AND APPARATUS FOR PROCESSING A SIGNAL IN A TELECOMMUNICATION APPARATUS



(57) Abstract

The invention relates to a method and an apparatus for processing a signal in a telecommunication apparatus. According to the method the signal is fed to a telecommunication channel (10), the signal is processed with a linear adaptive receiver equalizer (16) and possibly a decision feedback adaptive equalizer (30). According to the invention the equalization (H(z)) of the sections of the fixed band stop filters (14, 15) located in the transmitter (50) and the receiver (60) is performed at the transmitter end (50) prior to the band stop filtering (14) of the transmitter (50).

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CN	China
CU	Cuba
CZ	Czech Republic
DE	Germany
DK	Denmark
EE	Estonia
ES	Spain
FI	Finland
FR	France
GA	Gabon
GB	United Kingdom
GE	Georgia
GH	Ghana
GN	Guinea
GR	Greece
HU	Hungary
IE	Ireland
IL	Israel
IS	Iceland
IT	Italy
JP	Japan
KE	Kenya
KG	Kyrgyzstan
KP	Democratic People's Republic of Korea
KR	Republic of Korea
KZ	Kazakstan
LC	Saint Lucia
LI	Liechtenstein
LK	Sri Lanka
LR	Liberia
LS	Lesotho
LT	Lithuania
LU	Luxembourg
LV	Latvia
MC	Monaco
MD	Republic of Moldova
MG	Madagascar
MK	The former Yugoslav Republic of Macedonia
ML	Mali
MN	Mongolia
MR	Mauritania
MW	Malawi
MX	Mexico
NE	Niger
NL	Netherlands
NO	Norway
NZ	New Zealand
PL	Poland
PT	Portugal
RO	Romania
RU	Russian Federation
SD	Sudan
SE	Sweden
SG	Singapore
SI	Slovenia
SK	Slovakia
SN	Senegal
SZ	Swaziland
TD	Chad
TG	Togo
TJ	Tajikistan
TM	Turkmenistan
TR	Turkey
TT	Trinidad and Tobago
UA	Ukraine
UG	Uganda
US	United States of America
UZ	Uzbekistan
VN	Viet Nam
YU	Yugoslavia
ZW	Zimbabwe

INTERNATIONAL SEARCH REPORT

International application No.
PCT/FI 98/00353

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H04L 27/01

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CA 2153641 A1 (TELECOMMUNICATIONS RESEARCH LABORATORIES), 12 January 1997 (12.01.97), figures 3-5, claims 1,4, abstract -- --------	1-10

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
13 November 1998	13 -11- 1998
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. + 46 8 666 02 86	Authorized officer Rune Bengtsson Telephone No. + 46 8 782 25 00

INTERNATIONAL SEARCH REPORT

Information on patent family members

05/10/98

International application No.
PCT/FI 98/00353

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
CA 2153641 A1	12/01/97	NONE	